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EVALUATION OF VITRIFYING MUNICIPAL INCINERATOR ASH

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ABSTRACT

The management of municipal solid waste (MSW) is becoming a national problem. Landfills are being closed and new landfills are not projected to meet future needs. Incineration provides significant volume reduction of MSW, but the resulting ash can concentrate undesirable organics and heavy metals. Vitrification of the ash is a very attractive means for treating this ash stream. It provides further volume reduction, destroys any organic residues, and immobilizes heavy metals. In addition, the vitrified ash can become a useful construction material. Thus, vitrification can transform a waste material into a useful product and without requiring any landfill capacity. The feasibility of vitrifying MSW incinerator ash produced by an existing incineration facility in Whatcom County, Washington, was evaluated technically and economically. Vitrification of the incinerator ash provides an 80 volume percent reduction, forms a homogeneous glass, and is estimated to be economically favored over transportation and disposal of ash for the Whatcom County site by over $25 dollars per ton of ash. The vitrification cost per ton of ash is about $53. When assigned to the original ton of MSW, the vitrification cost is about $20 dollars per ton of MSW. Thus, vitrification of MSW incinerator ash provides an economic treatment method while providing an environmentally sound solution to another potentially troublesome waste stream.

INTRODUCTION

In early calendar year 1990, Recomp of Washington (ROW) and Pacific Northwest Laboratory (PNL) reached an agreement to assess the feasibility of using U.S. Department of Energy (DOE)-developed vitrification technology for vitrifying MSW incinerator ash. This work was co-funded by DOE and Recomp, Inc[1]. ROW manages an MSW incineration plant in Whatcom County, Washington near the city of Bellingham in northwestern Washington State. The approach for this work was to characterize plant operation, estimate ash composition and variability based upon existing data, complete laboratory experiments and analyses to assess technical feasibility, and create a preliminary cost estimate for ash vitrification. This paper summarizes this evaluation.

[1] Recomp, Inc., Salt Lake City, Utah

Background and Future Plans

ROW currently incinerates 100 tons of MSW per day with two Consumat CS-2000 incinerators. The incineration facility includes a waste heat steam generator and produces about 1,200 kilowatts of electricity. In the summer of 1990, the electrostatic precipitator was replaced by a dry acid gas scrubber and a bag house, off-gas cleanup system. By the summer of 1991, the plant will also include a materials recovery and on-site composting facility. A new mushroom-growing plant will use the waste heat from the electric generating turbine's condenser. This heat will control the growing environment for mushroom production. Later in 1991 an ash vitrifier is planned to become operational. After all of these systems become operational, this plant will represent a state-of-the-art MSW facility.

CHARACTERIZATION OF RAW MUNICIPAL SOLID WASTE

To evaluate the feasibility of vitrifying MSW incinerator ash, the composition and variability of the ash needed to be understood. To estimate the general composition, the characterization of MSW was investigated. Data on national, regional, and county refuse compositions were obtained from previous studies and compared. The U.S. Environmental Protection Agency (EPA) has sponsored annual assessments of the composition of MSW (1). A similar study was supported in Whatcom County (2); results from that study and the EPA study are compared in Figure 1. Assuming the classification techniques used in the two studies were similar, the main differences between the composition of wastes for Whatcom County and the national averages are that quantities of paper, yard and garden waste, and glass are lower than the national average, while the quantity of wood is higher. These differences would not appear to have a significant impact on the overall ash composition. Thus, use of ash data from other national studies would appear to provide an acceptable estimate for the Whatcom County facility.

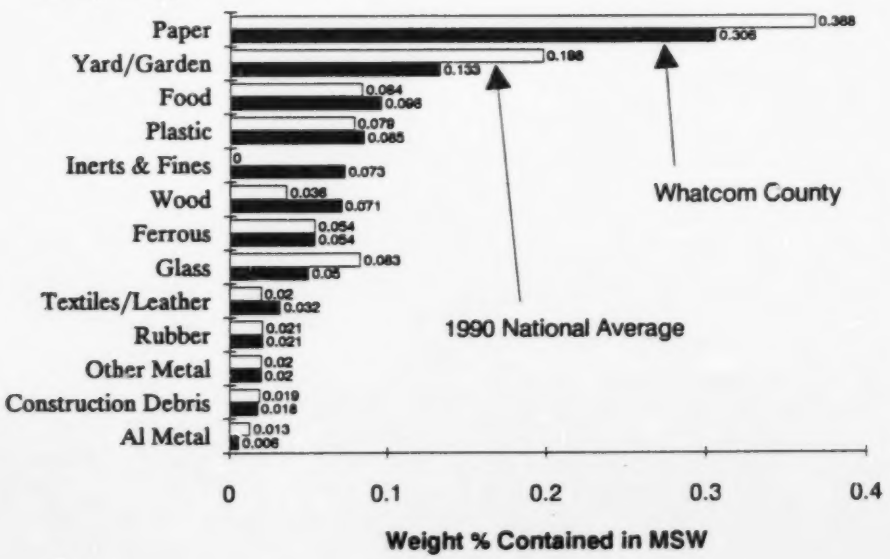

Figure 1 Composition of MSW by General Categories

CHARACTERIZATION OF MSW INCINERATOR ASH

Ash compositions from several plants have been reported by the EPA (1) and are summarized in Table 1. For the work described here, selected ash sample from the ROW plant was analyzed. The weight fractions for the various constituents in that sample are reported in the last column of the table. As indicated, this ash sample had a relatively high concentration of carbon. The subsample contained char residue from a wood fragment that apparently biased the sample. A comparison of the major constituents such as silicon, calcium, and aluminum is fair to good, while the iron concentration appears low. A notable difference in chlorine content exists between the EPA-reported average and the Whatcom County ash. This is understandable because an acid gas scrubber did not exist at the Whatcom County facility at the time of this sampling. The other significant difference in ash compositions was due to an apparently much higher concentration of sodium. Table 2 transforms the elemental data in Table

Table 1. Comparison of Measured Ash Compositions

Reported Combined Bottom and Fly Ash Concentrations in ppm

	Elemental Concentrations			Whatcom County
Element	Min.	Max.	Average	Sample
Silicon	88,813	294,017	191,415	236,000
Calcium	4,100	183,678	85,526	65,400
Aluminum	5,000	68,801	41,296	43,800
Iron	690	133,500	52,773	31,100
Zinc	2,120	46,000	21,307	2,500
Titanium	1,000	28,000	14,500	5,080
Chloride	766	44,200	22,483	2,300
Lead	31	36,600	15,025	1,600
Magnesium	700	16,000	9,029	7,100
Sodium	1,100	33,300	12,820	50,400
Phosphorus	290	5,000	2,645	3,900
Potassium	290	12,000	7,618	1,000
Nickel	13	12,910	6,462	
Copper	40	9,330	3,949	2,020
Manganese	14	3,130	1,253	590
Barium	79	2,700	993	830
Chromium	12	1,500	556	30
Strontium	12	640	326	250
Boron	24	174	99	400
Tin	13	380	197	
Molybdenum	2	290	146	
Vanadium	13	150	82	
Cadmium	0	152	68	<20
Lithium	7	37	22	60
Arsenic	3	56	31	<400
Silver	0	93	28	10
Mercury	0	25	11	<.42
Total	105,132	932,898	490,748	686,570

Table 2. Comparison of Ash on Oxide Basis

Oxide Concentrations in Wt %

Element	Min.	Max.	Average	Whatcom County Sample	Whatcom County Ash Glass Sample
Silicon	19.0	62.9	41.0	50.5	48.50
Calcium	0.6	25.7	12.0	9.2	11.30
Aluminum	0.9	13.0	7.8	8.3	9.45
Iron	0.1	19.1	7.5	4.4	20.10
Zinc	0.3	5.7	2.7	0.3	0.56
Titanium	0.2	4.7	2.4	0.8	1.10
Chloride	0.1	4.4	2.2	0.2	
Lead	0.0	3.9	1.6	0.2	0.22
Magnesium	0.1	2.7	1.5	1.2	1.50
Sodium	0.1	3.6	1.4	5.4	
Phosphorus	0.1	1.8	0.9	1.4	0.83
Potassium	0.0	1.4	0.9	0.1	
Nickel	0.0	1.3	0.6		
Copper	0.0	1.2	0.5	0.3	0.10
Manganese	0.0	0.4	0.2	0.1	0.22
Barium	0.0	0.3	0.1	0.1	0.17
Chromium	0.0	0.2	0.1	0.0	0.08
Strontium	0.0	0.1	0.0	0.0	0.10
Boron	0.0	0.1	0.0	0.1	0.37
Sulfur				0.4	
Total	21.5	152.6	83.6	83.1	94.60

1 into oxides. A separate ash sample was oxidized and melted and its composition was measured; results are listed in the far right column of Table 2. The major variation in the expected glass composition for the ash glass is the lower concentration of silica and much higher concentration for the iron in the melted ash glass. Otherwise, the comparison between the Whatcom County, EPA average, and ash glass shows surprising similaritics.

Physical and Thermal Characteristics of Incinerator Ash

To develop a preliminary flowsheet for vitrifying bottom ash, some of the physical and thermal characteristics of the materials were measured. Calorimetry, weight loss, and density for the various forms of the ash were determined and are reported here. Two 20-kilogram, arbitrary samples from 33,000 cubic meters of stored ash were taken for characterization. At the ROW facility, the ash is discharged from the incinerator into a water quench trough. A mechanical drag conveyor removes the ash from the trough and discharges it. Excess water drains from the ash to the leachate collection system. Periodically, the ash is loaded into a truck and transported to the ash pile from which these samples were taken.

Moisture Content. Four 2-kilogram samples of the ash pile material were oven dried at 105 °C. The moisture content ranged between 29 and 37 wt% and averaged 31.5 wt%.

Calorimetry of Bottom Ash. A small subsample from the discharged ash was measured for energy content. A 2-gram subsample of ash was placed in a calorimetry bomb. The energy released from this sample was 826 calories per gram, or about 1,450 BTUs per pound of dried ash. This measurement seems high and may not be representative of the average ash. A similar test was completed for a fly ash sample, but no energy content was measured.

Physical Characteristics of Ash. The densities for the different forms of the MSW were measured and are reported in Table 3. The density of the ash and ash glass were measured, while the values for the MSW were taken from the literature.

Table 3. Ash Material Properties and Relative Characteristics

	Density (kg/m^3)	Weight (kg)	Volume (m^3)	Volume % of MSW	Weight % of MSW
MSW	241	1,000	4.15	100.0	100.0
Quenched Ash	1,202	460	0.38	9.2	46.0
Ash Pile Ash	1,053	382	0.36	8.7	38.2
Oxidized Ash	642	232	0.36	8.7	23.2
Glass	2,859	221	0.08	1.9	22.1

CHARACTERIZATION OF VITRIFIED ASH

Samples of the combined ash were oxidized by isothermal treatment at 750 °C for up to 24 hours. Oxidation was assumed complete when no further weight loss was noted after 2 hours. Ash glass was made from 100 to 300 grams of oxidized ash by heating at 1500 °C for 1 to 2 hours. The typical resulting melt is depicted in Figure 2.

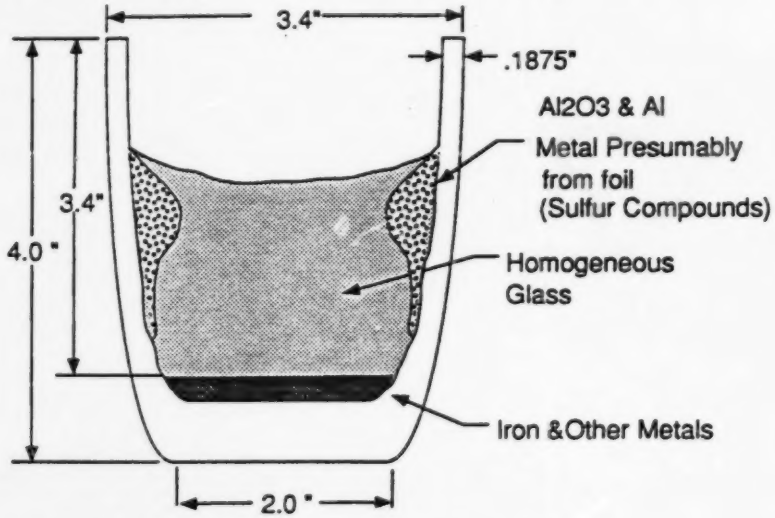

Figure 2 Typical View of Crucible after Ash Heated at 1500 °C for One Hour

As shown in Figure 2, molten iron collected at the bottom of the crucible. The bulk of the melt was a homogenous glass up to the top surface, which was typically composed of an unmelted rim. This rim was enriched with oxides of aluminum. Apparently, aluminum metal in the ash melted, beaded to the surface, and slowly oxidized around the periphery. This portion of the heated mass typically did not melt into the molten glass within 2 hours. Sulfur compounds were apparently present, as indicated by the pungent sulfur odor associated with this crusty layer. After melting from 6 to 14 hours at 1500 °C, the rim of enriched aluminum reacted with the bulk to form a homogeneous melt. The glass was a very lustrous, reflective, dark-black material. The densities of several glass shards were measured to be between 2.75 to slightly more than 3 grams per cubic centimeter. These shards were extracted from nine different ash glass melts. This high density is attributed to the high concentration of iron in this ash glass. The average density is as reported in Table 3.

Molten Ash Glass Properties

Arbitrarily drawn subsamples of the nine melts were combined and mixed in a shatter box. Electrical resistivity and viscosity measurements for the mixed MSW ash glass were completed and are presented in Figure 3.

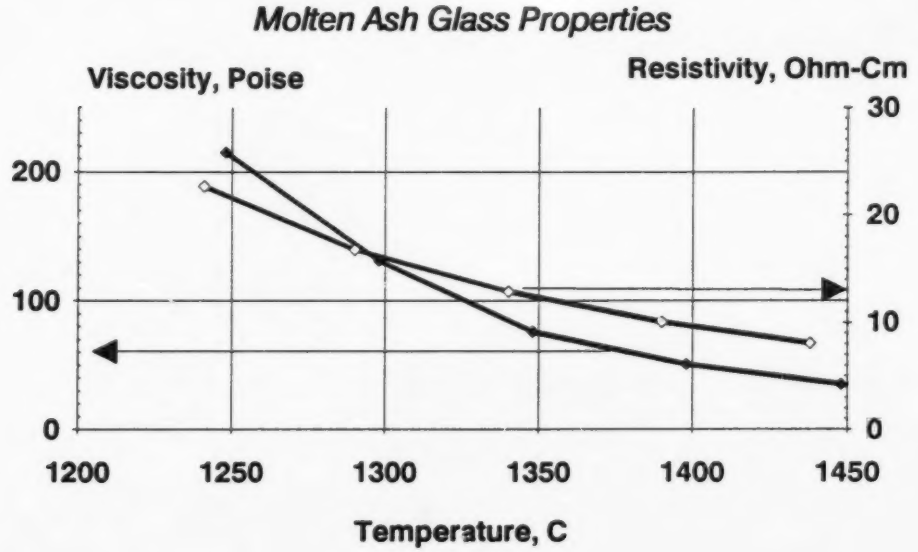

Figure 3 Properties of Molten MSW Ash Glass

For this sample, the 100 poise melting temperature is about 1325 °C. The resistivity for this glass is relatively high, 12 to 13 ohm-centimeters, at a viscosity of 100 poise. Using a melting temperature of 1450 °C to 1500 °C, to assure melting of iron, this ash glass appears quite feasible for standard electric-heated glass melting. Based upon the

compositions, physical properties, and results from completed crucible melts, vitrification of incinerator ash appears to be a technically feasible approach for treatment of the ash.

ESTIMATED COSTS FOR ASH VITRIFICATION

For vitrification of incinerator ash to be a viable treatment option, its costs must be competitive with alternative approaches. The following discussion provides a cost estimate for vitrifying the ash at this plant, and compares those costs to those for the alternative of storage, transportation, and disposal at a licensed ash disposal site.

The objective of the process is to work off the existing stored ash, while concurrently processing the ash produced from the ongoing operation of the incinerator. The simplified flow sheet shown in Figure 4 shows the general arrangement for the vitrification process and its interface with the existing municipal waste incinerator. As indicated, the oxidation air used in the vitrifier is preheated from the incinerator's off-gas, thereby reducing energy requirements while achieving oxidation of the residual organics and carbon present in the ash. The vitrifier's off-gas is then discharged to the incinerator to pass through the existing incinerator's off-gas cleanup system. To work off the backlog of ash existing at the site in four years, while treating the ash produced from ongoing operations, the vitrifier needs to have a capacity of about 50 tons of moist ash per day. The simplified mass and energy balance for the system is presented in Table 4.

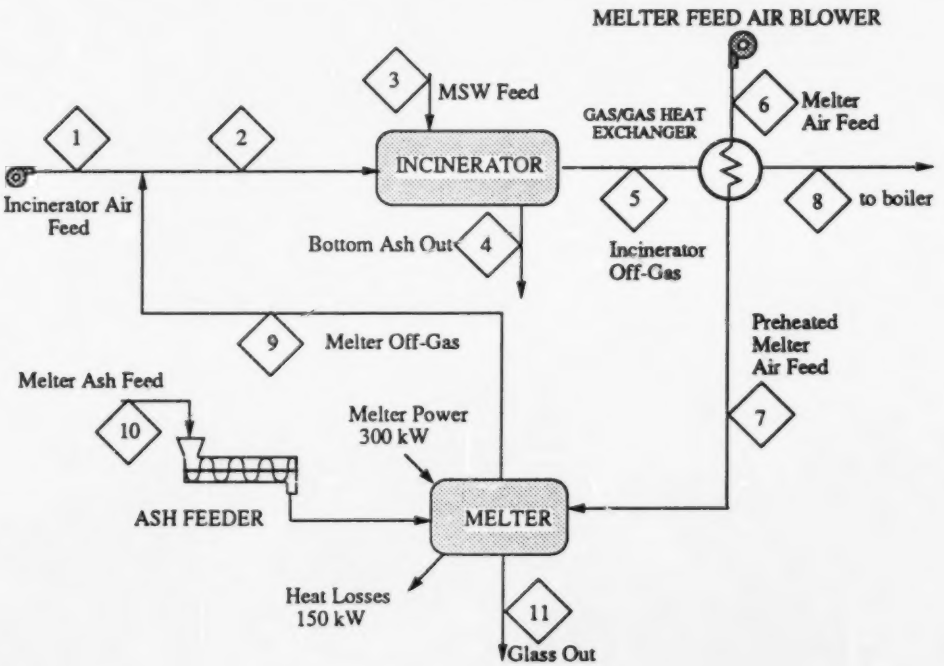

Figure 4 Flowsheet for Ash Vitrification

Table 4. Mass and Energy Balance for the Ash Vitrification

Stream #	1	2	3	4	5	6
Mass rate (kg/hr)	24,542	29,226	3,754	803	32,177	3,809
Power (kW)	12	1,912	10,939	500	12,351	2

Stream #	7	8	9	10	11
Mass rate (kg/hr)	3,809	32,177	4,684	2,067	1,192
Power (kw)	591	11,762	1,900	1,951	793

The proposed system includes the melter, the heat exchanger in the incinerator's off-gas stream, and the ash-feeding system, but excludes the cost of the existing off-gas cleanup system. The capital cost for the equipment and its installation and engineering costs was estimated to be less than $1.2 million dollars. This estimate includes a 20% contingency for equipment and its installation. The relatively low capital cost for this system is due primarily to an innovative melter design, which emphasizes economy in operation and minimum capital cost. An estimate of the operating costs, including capital recovery, is presented in Table 5.

A relatively low electric energy demand from the melter is due primarily to the use of the combustion energy from the residual char and organics in the waste ash feed. The value for consumption of graphite from the electrodes is believed to be conservatively high. It is a value consistent with smelting ash melters, but it should be lower for a joule heating graphite electrode because arc losses are not present. Smith (4) reports that they have achieved about a year's life from high-density graphite in a lime glass. If this performance could be achieved, the electrode cost per ton of ash would be about $0.16. The chemical costs are assigned a zero value because the ash melts with no additions at temperatures ranging from 1300 °C to 1500 °C. The benefit of combining the operation of the ash melter with that of the incinerator is realized in the reduced labor cost. One individual is assigned the responsibility for full-time attendance of the feeding and frit discharge, while periodically the incinerator operator is assumed to be needed for melter adjustment and monitoring. The capital recovery of 5 years, at an interest rate of 11%, is the assigned cost for processing the waste. Further capital cost reductions are believed possible, but for conservatism are not used for this study.

ALTERNATIVE COST FOR ASH MANAGEMENT

The alternative approach for managing the ash from the incinerator is to continue with the current mode of operation. This requires the ash being discharged from the incinerator to be analyzed on a frequency and by a procedure defined by Washington State Department of Ecology. This yearly cost that is assigned to the ash is as indicated. The ash pile is placed in a monofill that contains and precludes the release of any leachate from the pile. This leachate water, due to rain or the further drain-off of water from the quenched ash, is directed towards the municipal sewage water treatment facility and has the assigned costs as indicated. This practice, after treatment of the old ash, will not be needed if the ash is vitrified. Thus, it is shown here as a cost for ash management but not for vitrification. The dominant cost for the ash is its transport and disposal in an ash disposal site. Transportation with a one-way cost of 10 cents per ton mile accounts for $32.00 of the cost, while the estimated disposal charge is $35.00 per ton.

Based on these estimates, vitrification of the ash is cost competitive by up to $25 per ton of ash, or over $9 per ton of original MSW. The cost for vitrification assigned to the original ton of MSW is approximately $20 per ton. Thus, vitrification of MSW incinerator ash at the Whatcom County facility appears to be economically feasible.

Table 5. Comparison of Ash Vitrification Costs to Ash Disposal Costs

Cost Category	Units	Units per ton of MSW	$ per unit	$ per ton of MSW	$ per ton of old ash	$ per ton of ash glass
Electric Energy	Kw-Hr	55.10	0.03	1.65	4.32	7.51
Electrode	#	1.91	1.06	2.02	5.30	9.16
Chemical	#	0.00	0.10	0.00	0.00	0.00
Labor	man-days	0.03	210.00	7.23	18.90	32.87
Maintenance (5% of Capital Cost/yr)				1.63	4.26	7.41
Capital Recovery (5 yr,11%)				7.34	19.19	33.37
Accumulated Metals Operations				0.50	1.31	2.27
Total Vitrification Costs				**20.38**	**53.27**	**92.65**
Ash analysis ($/ton MSW) $127k/yr		3.78	1.00	3.78	9.88	17.19
Ash Leachate Water Treatment				0.63	1.65	2.86
Ash Transport to Disposal	ton mile	122	0.1	12.24	32.00	55.66
Final Disposal Charge				13.39	35.00	60.88
Present Worth of Future Liability				?	?	?
Ash Disposal Costs				30.05	78.53	136.59
Vitrification Cost Advantage				**9.67**	**25.26**	**43.94**

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